# APPENDIX B

# COMPUTING ALERT ONSET TIMING REQUIREMENTS

# B COMPUTING ALERT ONSET TIMING REQUIREMENTS

## B.1 Introduction

This appendix presents equations to compute ranges (distances) at which a forward collision warning (FCW) system needs to present crash alerts to a driver. These ranges depend on the speeds and accelerations of the FCW-equipped vehicle and another vehicle that is ahead. These equations are quite similar to those in Chapter 4, Section 4.2.3.1 (Crash Alert Timing and Crash Alert Timing Adjustability). There are differences, however, that may be significant when actually computing requirements for specific situations. These differences include:

- A precise description of the domain of validity of the equations is provided,
- The equations may be used in some non-closing situations (e.g., when the lead vehicle is accelerating), unlike those in the report body,
- A specific computation is presented to determine which kinematic "case" is expected, that is, whether the lead vehicle is expected to be stopped or moving at impact, and
- The equations handle all special cases that fall within the stated domain of validity (e.g., all divide-by-zero errors and ambiguities are eliminated).

The equations in this appendix are referenced throughout the body of the report. In Chapter 3, the alerts presented to subjects in the human factors experiments are consistent with these equations. Chapter 4 recommends alert onset timing requirements; the equations in this appendix allow one to compute the requirements for all conditions within the stated domain of validity. Because those requirements are a basis for the objective test procedures described in Chapter 5 and evaluated in Chapter 6, the equations are referenced in those chapters as well.

Note that although the computational procedure presented in this appendix could serve as a starting point for designing alert onset timing for FCWs, the algorithm is *not* required to be part of an FCW system. Furthermore, the algorithm presented in this chapter is not intended to handle all potential rear-end collision situations, nor is it intended to handle all possible operational situations. Further remarks on this subject are found later in this appendix.

Two sections follow within this appendix. First, the approach to alert onset timing requirements presented in Chapter 4 is reviewed. Second, the algorithm is presented and limits of the validity of the equation are described.

# B.2 Review of Approach to Alert Onset Timing Requirements

Chapter 4 describes the circumstances in which FCW alerts are required, allowed, or not allowed. Many factors are considered in this determination, including aspects of the SV's motion, the presence of a potentially threatening object and its characteristics, and the relative positions and motion between the SV and the threat. (See Chapter 4 for a complete description of requirements.) In this appendix, however, assume that all conditions are such that determining whether an alert is required, prohibited, or is allowed, depends only on the alert onset timing – that is, the longitudinal distance between the vehicles and their speeds and accelerations.

The approach to minimum requirements for alert onset timing that is presented in Chapter 4 requires that the onset of FCW crash alerts occurs with a timing that is neither "too early" nor "too late," given the existing speeds and accelerations of the vehicles. A key finding in the first human factors study in Chapter 3 is that the timing of drivers' decisions to begin last-moment braking can be modeled well by considering the deceleration required to avoid impact. Since a driver requires a finite time to perceive the alert, react, and finally press the brake pedal, it follows that a valid approach to last-moment alerts is one in which an alert is given at the last moment possible to account both for the driver reaction time and the distance that the driver's vehicle closes on the lead vehicle before the driver can bring the vehicle's speed down to that of the lead vehicle.

The requirement specifications of "too early" and "too late" are each expressed using an alert range that is computed using the two vehicles' speeds and the accelerations. The same set of equations is used to compute the two bounds, however, a pair of parameters within the equations is assigned one set of values for "too early" and another set for "too late." Consider a lead vehicle – a "principal other vehicle" (POV) – and a following "subject vehicle" (SV) which is equipped with an FCW system. The two specifications each correspond to the minimum range at which an alert would be required to bring the SV speed down to the POV's speed with no range remaining (just touching bumpers) under the following assumptions:

- SV braking would begin only after a known delay time after the alert onset.
- SV braking (after the delay) may be modeled as a constant acceleration value that may depend on vehicle speeds and acceleration values at the time of alert onset.
- The minimum range considers the POV's acceleration at the time of alert onset, and assumes that the POV acceleration will remain constant throughout the event, unless the POV comes to a stop (in which case the POV is assumed to remain at rest).

Up to this point, the approach stated above is not new to this project. The unique aspect of the timing approach suggested in this report is that the parameters used to describe the delay time and the SV braking level is based on the human factors experiments (as described in Chapter 4 and elaborated on later in this appendix).

Those experiments:

1. Demonstrated that the general timing approach is consistent with a model of last-second braking decisions by drivers without an FCW.

2. Generated sets of parameters that can be used in the equations that yield alert timing that is simultaneously timely and not annoying (the parameters describe driver braking reaction times and braking levels).

3. Demonstrated driver acceptance and acceptable performance, given alert timings with such an approach.

# B.3 Equations to Compute Alert Timing Requirements

The approach to alert onset timing requirements is based on observed braking decisions of drivers, as described in Study 1 of Chapter 3. To compute numerical values for the alert requirements for a given situation, however, requires using a set of equations that may appear somewhat lengthy, and that become more complicated as more sets of initial conditions are addressed. The straightforward application of the simple kinematics and the simple model of driver response to alerts require handling many possible "cases" of initial, intermediate, and final kinematic states. The number of cases that is to be handled is familiar to any designer or analyst that has translated the simple timing approach above into a warning algorithm, and tested the algorithm either in simulation or in a vehicle. The inclusion of the new driver response parameters does not significantly complicate the computations.

This section presents a set of equations that should be used to evaluate the alert onset timing of an FCW being evaluated with the vehicle-level objective test procedures described in Chapter 5. The equations provide the "too early" and "too late" alert onset ranges for any given set of vehicles speeds and accelerations that fall within the limited set of initial conditions described. This set of initial conditions includes those that will occur at or near alert onset in the objective test procedures. These equations do *not* constitute a complete warning algorithm and should not be used as such. Although the equations also provide suitable alert timing for many common potential rear-end crash situations – including the conditions seen both in the human factors experiments and in the objective test procedures of Chapter 5 – there will be other potential rear-end crash situations in which a more complete set of equations is needed. In addition, the equations in this appendix do not include additional logic used to handle situations in which the driver is already braking the host vehicle.

## B.3.1 Equations to Compute Alert Timing Requirements

The requirements are valid over a restricted domain of initial conditions. This domain of validity is now presented. Let $V_{SV}$ and $V_{POV}$ denote the initial speeds of the SV and the POV, respectively, as shown in Figure 1. Let $dec_{SV}$ and $dec_{POV}$ be the initial decelerations of the SV and the POV, respectively (negative values for braking). Let "Delay Time" denote the total delay time between the crash alert onset and when the driver decelerates the vehicle in response to the crash alert. The total delay time includes both the driver's reaction time and the nominal brake system lag. The driver's deceleration response is denoted $dec_{SVR}$, and this is negative for braking. The equations address the computation of the alert requirements; the following conditions are assumed:

- SV speed is initially at least 16 kph.
- POV speed is positive or zero, but is not negative.
- SV speed is expected to be greater than the POV speed at the end of the total delay time.
- SV acceleration at crash alert onset has an absolute magnitude that is no greater than 0.1g. This should hold during nearly all normal non-braking driving conditions.
- SV speed is not expected to go to zero during the delay.
- If the POV is initially moving, it will not come to rest during the delay.
- The POV is either decelerating or not accelerating more than 0.08g.

If any of these conditions do not hold, the equations that follow are not applicable for computing the requirements for alert timing.

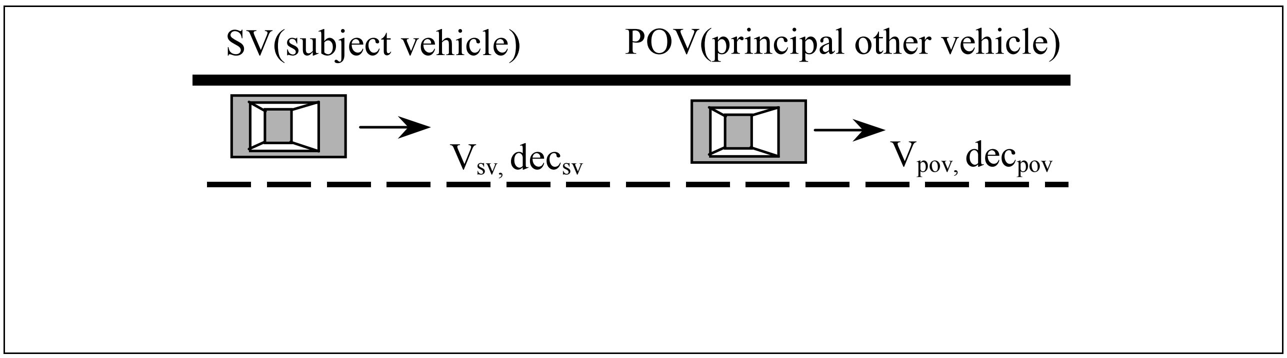


**Figure 1 Initial Situation of Vehicle Pair**

To compute alert requirements, four steps are suggested.

1. Project values for the speeds from the initial conditions to the end of the total delay time. The predicted speeds at the time of SV deceleration onset are:

$$V_{SVP} = V_{SV} + dec_{SV}*\text{Delay Time}$$

$$V_{POVP} = V_{POV} + dec_{POV}*\text{Delay Time}$$

2. Evaluate the expected driver braking response, $dec_{SVR}$, and the total delay time. As described in Chapter 4, the total delay time should be the sum of the assumed driver reaction time, plus an 0.200 sec value that represents a typical delay time between a rapid brake pedal application and deceleration of the vehicle. Chapter 4 states that to compute the minimum range at which the alert can begin, one should use a driver reaction time of 1.18 sec and a driver braking level

described by the CAMP ADP equation (the predicted values for speeds are to be used in the ADP equation):

Delay Time = 1.18 + 0.20 = 1.38 sec.

$dec_{SVR}$ (g's)= -0.260g –( 0.00725g/m/s)$V_{SVP}$

To compute the maximum range at which the alert may begin (for the minimum FCW setting), Chapter 4 states that a driver reaction time of 1.52 should be used, along with the CAMP RDP equation (with predicted speed values):

Delay Time = 1.52 + 0.20 = 1.72 sec.

$dec_{SVR}$ (g's)=-0.165g+(0.685g/g)*$dec_{POV}$*($dec_{POV}$<0)*($V_{POVP}$>0)

+0.080g*($V_{POVP}$>0) +(-0.00877g/m/s)*($V_{SVP}$ – $V_{POVP}$)

The conditional expressions in the equation above should be evaluated as one if the inequality is true, and evaluated to zero if it is false. For instance, the second term above includes two conditional expressions so that the term (0.685g/g)*$dec_{POV}$ is included only if the POV will be both moving and decelerating after the total delay time.

3. Compute the minimum range at which an alert would be needed so that the model of driver response would just bring the closing speed to zero as the range went to zero. (Derivations of the following equations are not presented. The equations follow from a straightforward application of kinematics using the simple models presented, and assuming the conditions above apply.)

The alert range, R, is the sum of the desired range at SV deceleration onset ("braking onset range," or BOR), plus the amount that the range will decrease during the total delay time ("delay time range," or DTR). The delay time range is

DTR = ($V_{SV}$ – $V_{POV}$)*Delay Time + 0.5*($dec_{SV}$ – $dec_{POV}$)*(Delay Time)$^2$

Brake onset range can be computed using one of two possible expressions. These correspond to whether the POV is expected to be moving or stopped when the "contact" occurs (contact is the moment at which the models predict the range rate and range both go to zero). The following conditional determines which of these two cases is expected:

If $dec_{POV}$*$V_{SV}$ <= $dec_{SVR}$*$V_{POV}$ – $dec_{POV}$*Delay Time*($dec_{SV}$ – $dec_{SVR}$),

Contact expected when POV is stopped (Case 3 in Chapter 4, Section 4.2.3.1)

Else,

Contact expected when POV is moving (Case 2 in Chapter 4, Section 4.2.3.1)

This inequality is based on a simpler equation that compares the expected stopping time for the POV with the sum of the total delay time and the expected stopping time of the SV. It was necessary to rearrange the inequality so it provides the correct answer (true/false) even when POV speed and/or POV acceleration is zero.

Contact with a stopped POV includes cases in which the POV is initially stopped as well as cases in which the POV decelerates to a stop during the SV's braking maneuver. In this case, the braking onset range BOR is the difference between the SV's expected stopping distance and the POV's expected stopping distance:

If $dec_{POV} = 0$,

$$BOR = (V_{SVP})^2/(-2*dec_{SVR})$$

Else,

$$BOR = (V_{SVP})^2/(-2*dec_{SVR}) - (V_{POVP})^2/(-2*dec_{POV})$$

The case in which contact is expected when the POV is moving includes cases in which the POV is not decelerating, and in fact is accelerating within the conditions assumed earlier. It also includes cases in which the POV is decelerating, but conditions are such that contact is still expected before the SV deceleration can occur quickly enough. One common situation leading to this case is when the SV is tailgating at higher speeds and the POV begins braking at significant levels. If contact is expected when the POV is moving the braking onset range is:

$$BOR = (V_{SVP} - V_{POVP})^2/(-2*(dec_{SVR} - dec_{POV})).$$

Regardless of which braking onset range equation is used, the alert onset range R is to be computed using:

$$R = BOR + DTR.$$

4. Apply other applicable requirements that may affect requirements of the range at alert onset (Chapter 4, Section 4.7). For example, if the first three steps above yield a maximum range ("too late" cut-off) that is greater than the maximum longitudinal extent of the alert zone (100 meters), then the "too late" cut-off is adjusted to this value. The reader is advised to be familiar with all requirements of Chapter 4, Section 4.7, which puts these computational procedures into context.